AD-A141 562 HIGH SPEED EJECTORS(U) FLIGHT DYNAMICS RESEARCH CORP VAN NUYS CALIF M ALPERIN 04 APR 84 AFOSR-TR-84-0430 F49620-81-C-0043 1/1

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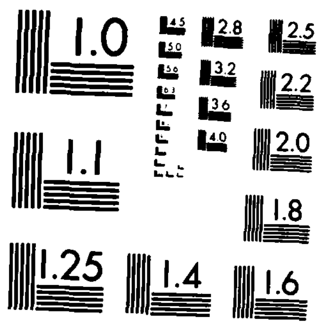

MICROCOPY RESOLUTION TEST CHART
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UNCLASSIFIED **AD-A141 562**

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A description of the test apparatus and some major experimental results are presented. The test apparatus is a pressurized test cell for simulation of translational motion by pressurization of the inlet flow to the corresponding stagnation pressure. The experiment consisted of measurement of the pressure distribution along the ejector surfaces and of the pressure, temperature and forces required to evaluate the mass flow, total forces and ram drag. In addition, Schlieren photographs were taken at each test to observe the flow and in particular to illustrate the shock wave patterns. Combination of the pressure distribution and Schlieren photographs illustrate the successful achievement of second solution flows. Further tests are to be performed to illustrate the optimization of second solution performance and for comparison between theory and experiment.

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22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. James Wilson	22b. TELEPHONE NUMBER (Include Area Code) (202) [illegible] 4935	22c. OFFICE SYMBOL AFOSR/NA

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Flight Dynamics Research Corporation
Annual Report - High Speed Ejector
Contract No. F49620-81-C-0043
April 1984

A-1

Research Objective

The ejector component models and their test set-up have been designed to provide measurement of the pressure distributions along the upper and lower surfaces of the ejector at various outlet area ratios and to measure the forces, and primary and secondary pressures and temperatures required to evaluate the mass flows and thrust augmentations at various ejector geometries and simulated flight conditions.

Status of the Research Effort

Test Set-up

The FDRC static test stand has been modified to accept the ejector model as illustrated on Figure 1. The primary, high pressure, ambient temperature air is supplied from a pressure vessel having a maximum pressure of 250 psig. The discharge from the pressure vessel is controlled by a remote valve and pressure regulator, through an orifice, to permit a controlled, adjustable pressure at the primary nozzles. To simulate the stagnation pressure due to translational flight, the secondary air is supplied from a Model RAS 60, 717 Roots Connersville displacement blower, through a system of tubes, orifices and valves. Its pressure is controlled by the use of a by-pass system permitting secondary air stagnation pressures to about 8 psig, simulating a flight Mach number of about 0.8.

The ejector is enclosed in a box capable of maintaining the secondary air and fitted with adjustable primary nozzles. The ejector component has a width of 3.0 inches and a height which has been varied from 0.25 inches to 1.0 inches, and a mixing length which can be varied from about 1.0 inches to about 3.5 inches. The outlet of the 1.0 inch ejector is remotely adjustable to provide a means for starting the second solution flow and for achieving the outlet area required for efficient operation of the second solution flow.

Test results

Table I is a summary of the tests performed on various ejectors having fixed and/or variable outlet geometries and variable primary pressures.

TABLE I

Config α_*	Throat width X_2	Outlet width X_E	Mixing length Z_m	Flight Mach No. M_∞	Remarks
7.55	0.25	0.25	2.5	0.5	DN
7.55	0.25	0.25	2.5	0.65	DN
7.55	0.25	0.25	2.5	0.81	DN
7.55	0.25	0.212	2.5	0.65	DN
7.55	0.25	0.212	2.5	0.81	DN
15.1	0.501	0.443	2.5	0.65	DN
15.1	0.501	0.443	2.5	0.81	DN
30.2	0.986	0.883	1.5	0.65	DN
30.2	1.000	0.906	2.5	0.5	DN
30.2	1.000	0.906	2.5	0.65	DN
30.2	1.000	0.906	2.5	0.81	DN
30.2	1.000	0.906	3.5	0.65	DN
30.2	1.000	0.906	3.5	0.81	DN
15.1	0.25	0.22	2.5	0.65	SCN Z_p=-.25
15.1	0.25	0.22	2.5	0.81	SCN Z_p=-.25
15.1	0.25	0.22	2.5	0.81	SCN Z_p=-.75
30.2	0.501	0.44	2.5	0.65	SCN Z_p=-.25
30.2	1.000	0.9-1.3	2.5	0.5	DN
30.2	1.000	0.9-1.3	2.5	0.65	DN
30.2	1.000	0.9-1.3	2.5	0.81	DN

DN - double array of nozzles
SCN - single array of central nozzles
Z_p - position of primary nozzles relative to entrance to mixing section

Pressure distributions along the ejector surfaces are presented on Figures 2 through 21.

Figure 2 illustrates the pressure distribution along the ejector surfaces at a simulated Mach number of 0.5 for the smallest ejector tested. As can be observed on Figure 2, the sharp pressure rise in the constant cross-section mixing section occurs at a primary plenum pressure (P_{op}) of about 65.3 psig, and proceeds downstream as the primary plenum pressure is increased. As shown on Figure 22, that rapid rise of pressure is a result of the presence of a starting shock wave. At a primary plenum pressure of 70.5 psig, the Schlieren photograph presented on Fig. 22 indicates the presence of a shock wave at about the center of the mixing section. As the primary plenum pressure is further increased, the shock wave progresses towards the exit of the ejector and reaches the end of the uniform cross-section at a plenum pressure of 85.1 psig.

Figure 3 illustrates the pressure distribution for the same ejector at a simulated flight Mach number of 0.65. At this increased flight Mach number the shock wave is able to exit the ejector and to form a system of oblique shock waves outside of the ejector, as shown for primary plenum pressures in excess of 80.3 psig. This is further corroborated by observation of Fig. 23, which depicts the external oblique system of shock waves. Thus it may be concluded that the ejector flow represents a second solution flow in a constant cross-section ejector.

The efficient operation of a second solution ejector requires a correct outlet configuration. Thus the geometry illustrated on Fig's 2 - 4 represents the achievement of a second solution ejector flow, however it is not efficient, since the outlet area ratio is not optimized, as described in Ref's 1 and 2. Further attempts to achieve second solution flows with ejectors having fixed outlets with area ratios less than 1.0 did not result in second solution flows, as illustrated on Figures 5 - 18.

Figures 5 - 18 depict pressure distributions of ejectors having outlet configurations theoretically designed for starting a second solution flow. However, these ejector outlets are within the one-dimensional geometric limitations of the first solution outlet designs, and therefore they default to the first solution, as explained in Ref. 3.

Further testing of the variable outlet ejector resulted in the pressure distributions illustrated on Fig's. 19 - 21. The results indicate that for those simulated flight Mach numbers and for outlet configurations which were not within the limitation of the first solution (X_e/X_2 greater than the first solution limit) the second solution flow was achieved. Thus as indicated on the Schlieren photograph of Fig 24, for $\alpha_* = 30.2$, $M_\infty = 0.81$, and $X_e/X_2 = 1.1$, at a primary plenum pressure of 75 psig, (an outlet area ratio which is greater than that prescribed for the limit of the first solution) the second solution has been achieved, since the shock wave can be observed in the diverging supersonic nozzle.

To achieve the desired goal of an efficient high speed ejector, it is intended to test the variable outlet ejector and to reduce the outlet area after starting the second solution flow at a larger outlet area. To perform those tests it is important to recalibrate the test rig and instrumentation, since the measurement of thrust augmentation on the present static test rig requires high accuracy in measurement of the pressures, temperatures and forces.

References

1. Alperin, M. and Wu J.J., "Thrust Augmenting Ejectors, Part I," AIAA Journal, Vol. 21, Oct 1983, pp 1428-1436.

2. Alperin, M. and Wu J.J., "Thrust Augmenting Ejectors, Part II," AIAA Journal, Vol. 21, Dec 1983, pp 1698-1706.

3. Alperin, M. and Wu J.J., "Remarks on Fabri and Siestrunck Supersonic Air Ejectors," to be published.

Publications

The papers published in technical journals are those listed as Ref's 1 & 2. A third paper (Ref. 3) has been presented to the AIAA Journal for publication and is presently being reviewed.

Personnel

Dr. Morton Alperin, Ph.D. 1950 Cal. Inst. of Tech.
Mr. Jiunn-Jenq Wu, Eng. 1971 Cal. Inst. of Tech.
Ms. Marilyn Stein, BS 1983 Univ. of Cal. Los Angeles

Interactions

A paper has been presented at the Ejector Workshop for Aerospace Applications at the University of Dayton, June 1982.

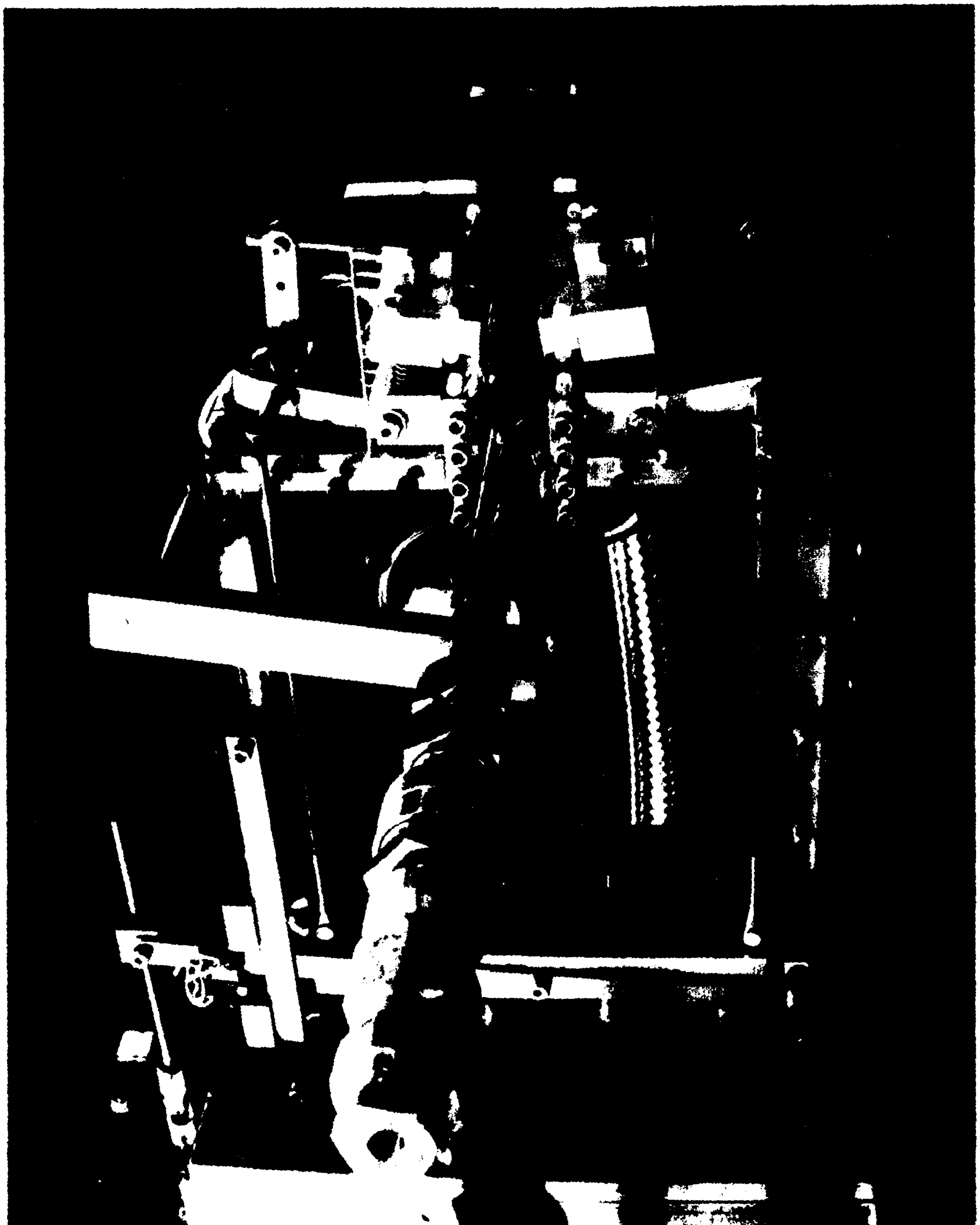


Figure 1. High Speed Ejector - Test Apparatus

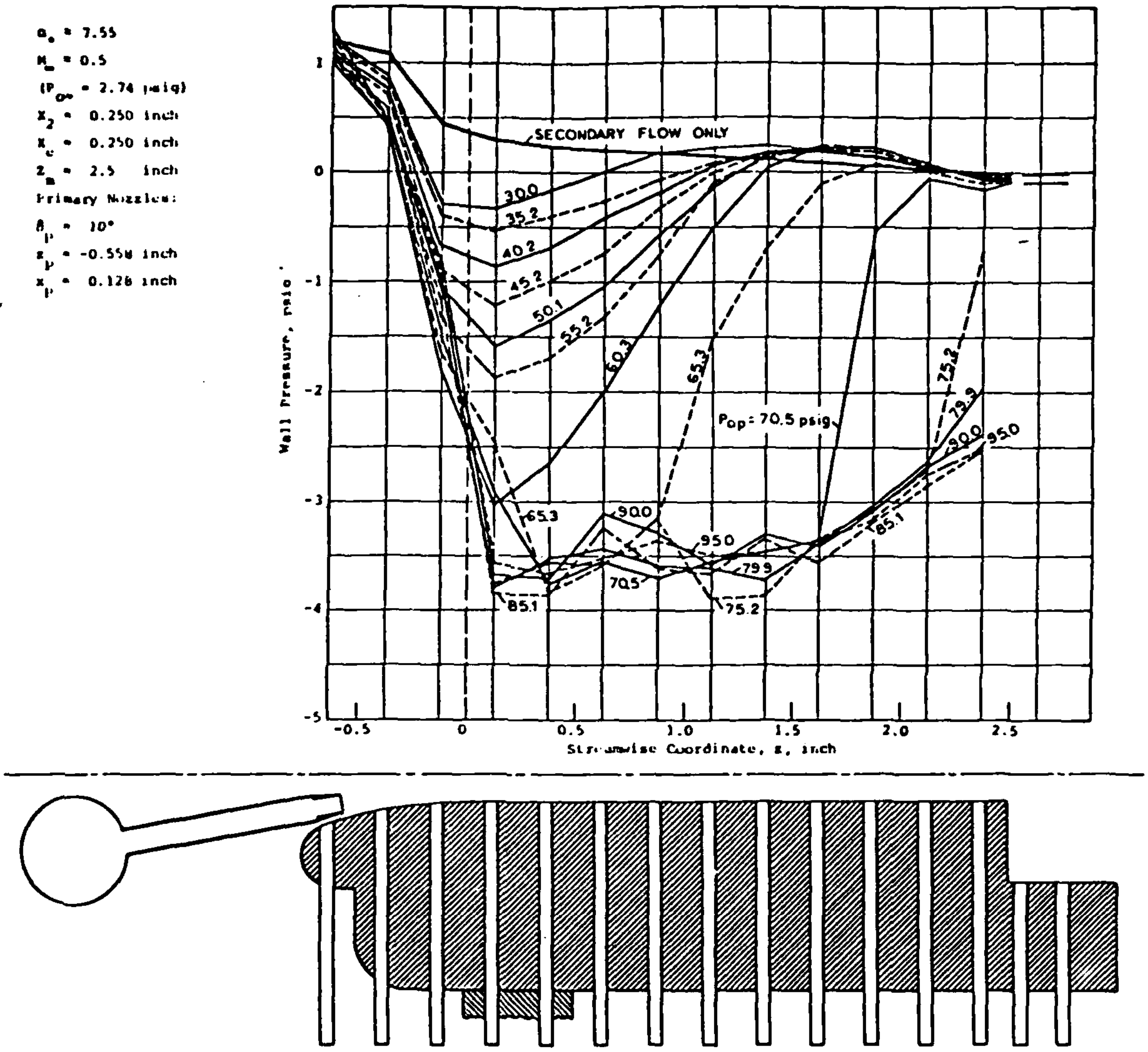

α_e = 7.55
M_∞ = 0.5
(P_0∞ = 2.74 psig)
x_2 = 0.250 inch
x_c = 0.250 inch
z_m = 2.5 inch
Primary Nozzles:
β_p = 10°
z_p = -0.558 inch
x_p = 0.126 inch
SECONDARY FLOW ONLY
30.0
35.2
40.2
45.2
50.1
55.2
60.3
65.3
P_op = 70.5 psig
75.2
79.9
90.0
95.0
85.1
70.5
Wall Pressure, psig
Streamwise Coordinate, z, inch
1
0
-1
-2
-3
-4
-5
-0.5
0
0.5
1.0
1.5
2.0
2.5

Figure 2

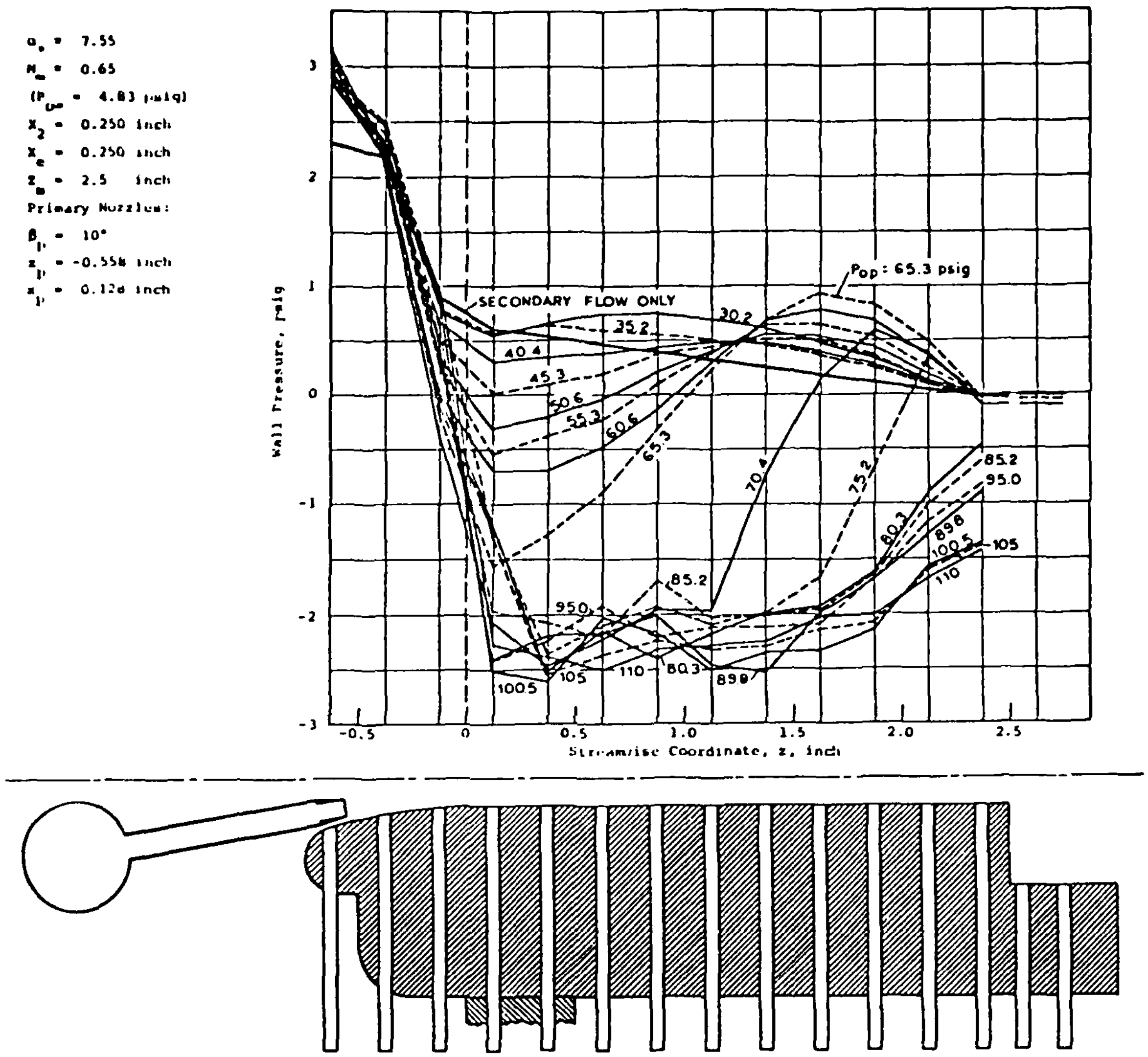
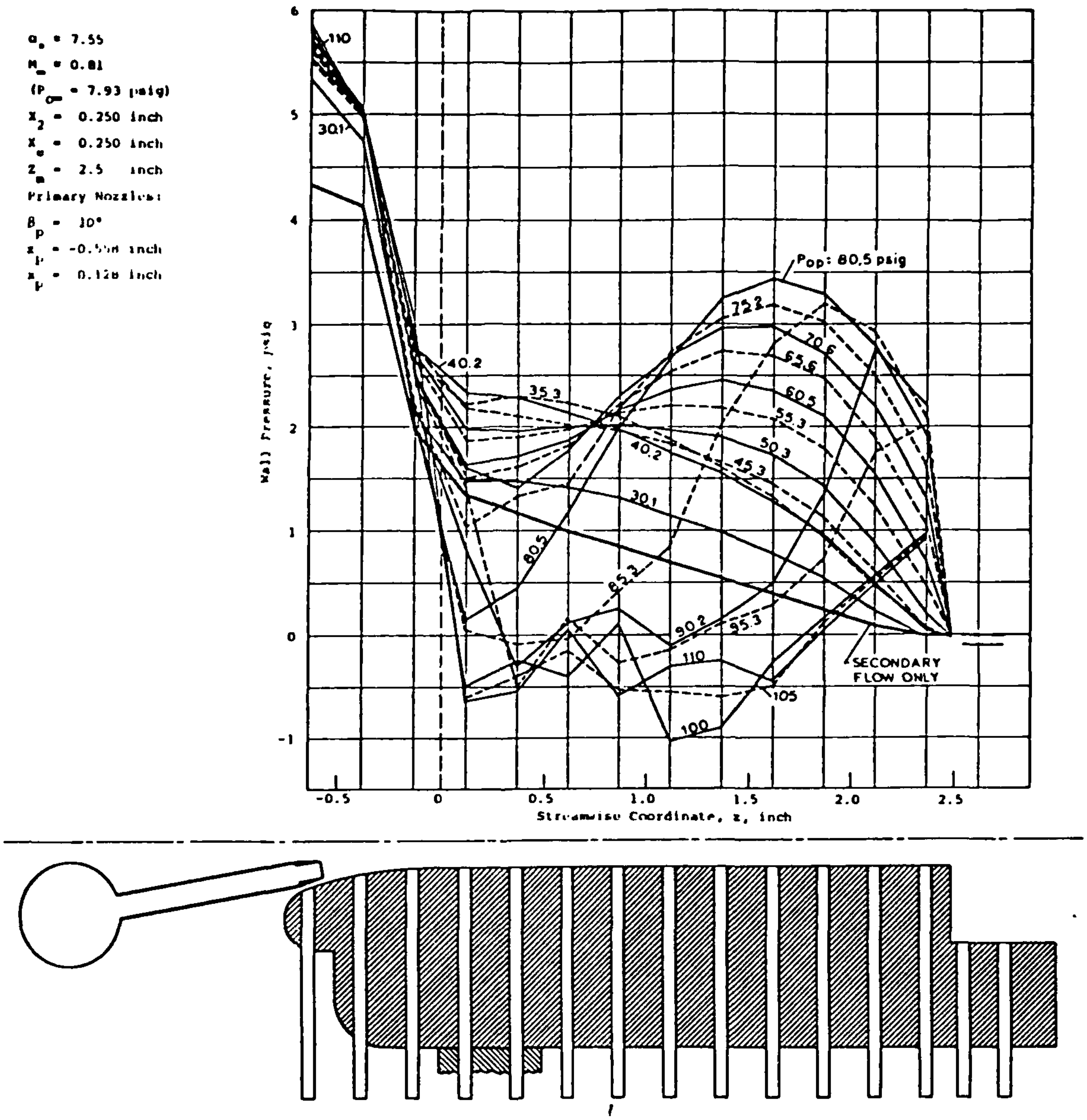
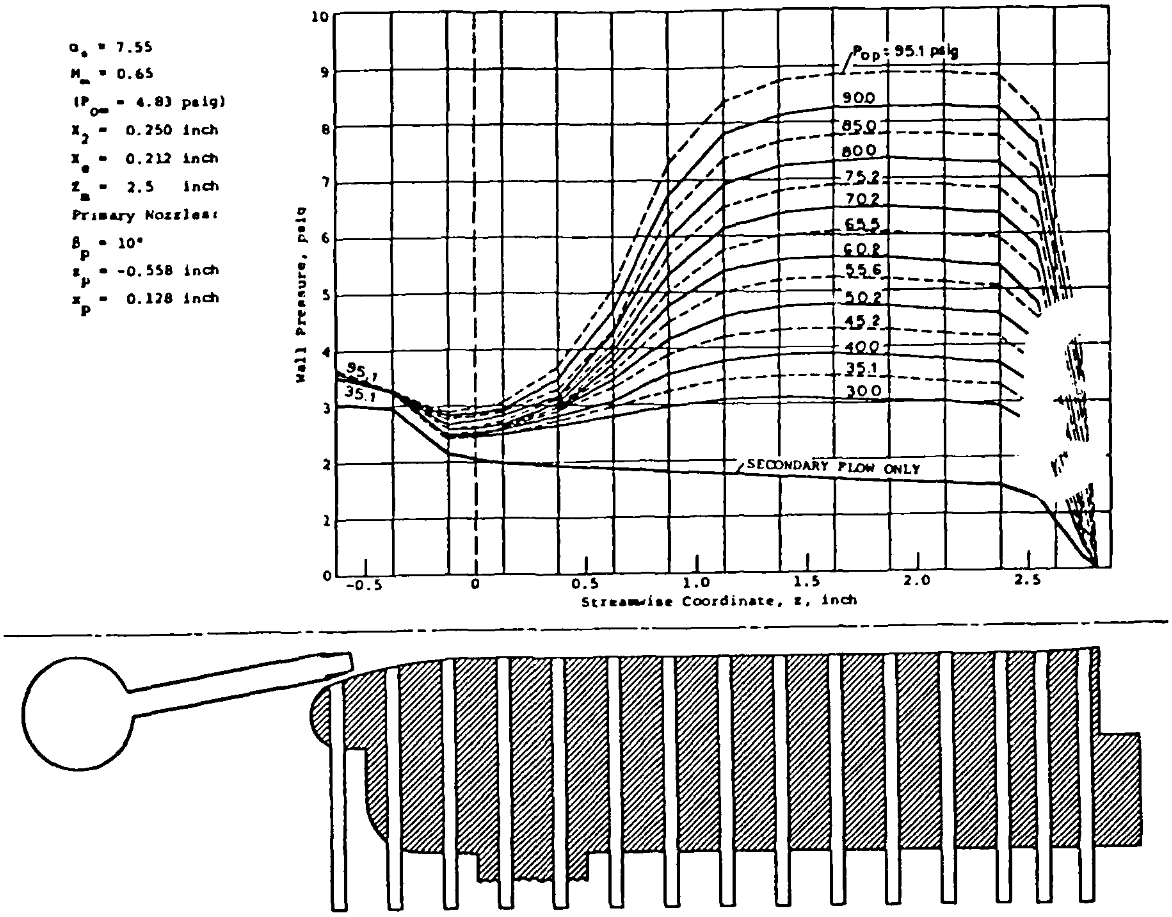

= 7.55
= 0.65
= 4.83
X_2 = 0.250 inch
X_e = 0.250 inch
= 2.5 inch
Primary Nozzles:
= 10°
Wall Pressure, psig
3
2
1
0
-1
-2
-3
-0.5
0
0.5
1.0
1.5
2.0
2.5
Streamwise Coordinate, z, inch
SECONDARY FLOW ONLY
P_{op}: 65.3 psig
30.2
35.2
40.4
45.3
50.6
55.3
60.6
65.3
70.4
75.2
80.3
85.2
89.8
95.0
100.5
105
110

Figure 3



α_s = 7.55
M_∞ = 0.81
($P_{o\infty}$ = 7.93 psig)
x_2 = 0.250 inch
X_e = 0.250 inch
z_m = 2.5 inch
Primary Nozzles:
β_p = 30°
x_p = 0.128 inch
Wall Pressure, psig
Streamwise Coordinate, z, inch
-0.5
0
0.5
1.0
1.5
2.0
2.5
-1
0
1
2
3
4
5
6
110
30.1
40.2
35.3
Pop: 80.5 psig
72.2
70.6
65.6
60.5
55.3
50.3
45.3
40.2
30.1
80.5
85.2
90.2
95.3
110
105
100
SECONDARY FLOW ONLY

Figure 4



α_e = 7.55
M_∞ = 0.65
($P_{0\infty}$ = 4.83 psig)
X_2 = 0.250 inch
X_e = 0.212 inch
Z_m = 2.5 inch
Primary Nozzles:
β_p = 10°
z_p = -0.558 inch
x_p = 0.128 inch
P_{0p} = 95.1 psig
90.0
85.0
80.0
75.2
70.2
65.5
60.8
55.6
50.2
45.2
40.0
35.1
30.0
95.1
35.1
SECONDARY FLOW ONLY
Wall Pressure, psig
Streamwise Coordinate, z, inch
-0.5
0
0.5
1.0
1.5
2.0
2.5
0
1
2
3
4
5
6
7
8
9
10

Figure 5

$\alpha_s = 7.55$
$M_\infty = 0.81$
$(P_{0\infty} = 7.93$ psig)
$X_2 = 0.250$ inch
$X_e = 0.212$ inch
$Z_m = 2.5$ inch
Primary Nozzles:
$\beta_p = 10°$
$z_p = -0.558$ inch
$x_p = 0.128$ inch

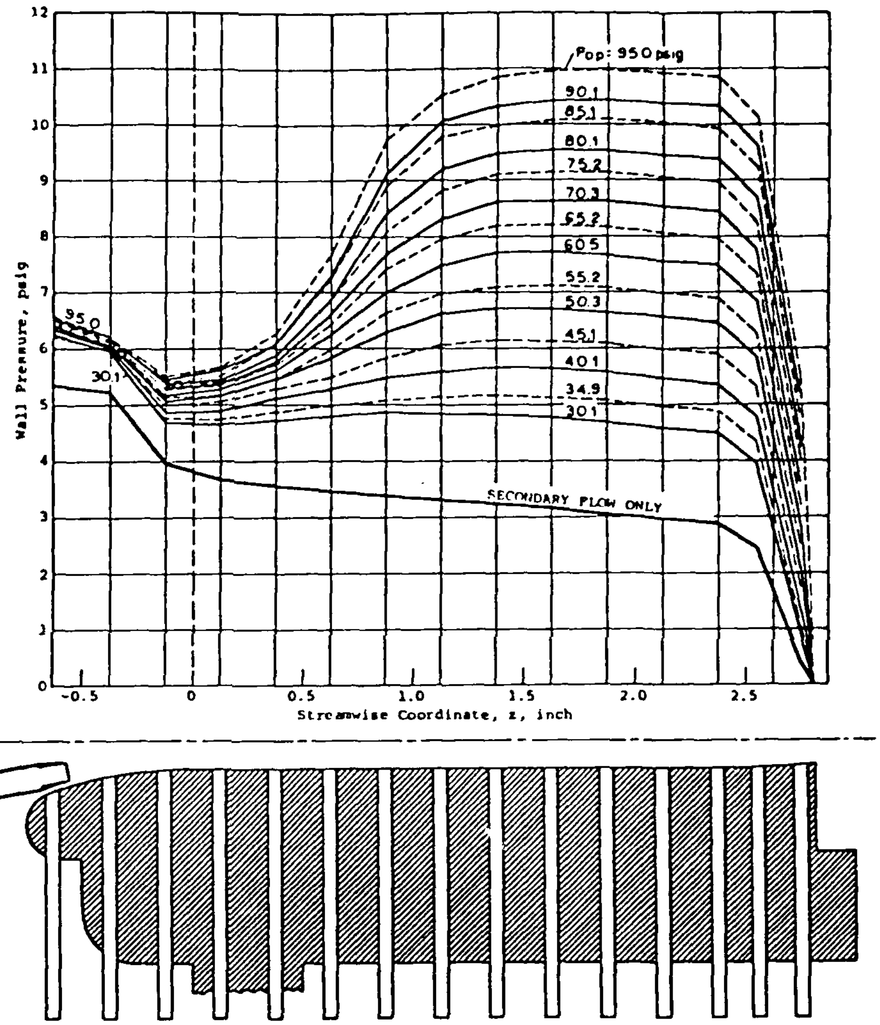


Figure 6

$\alpha_s = 15.1$

$M_\infty = 0.65$

$(P_{0\infty} = 4.83$ psig)

$X_2 = 0.501$ inch

$X_e = 0.443$ inch

$Z_m = 2.5$ inch

Primary Nozzles:

$\beta_p = 10°$

$z_p = -0.565$ inch

$x_p = 0.209$ inch

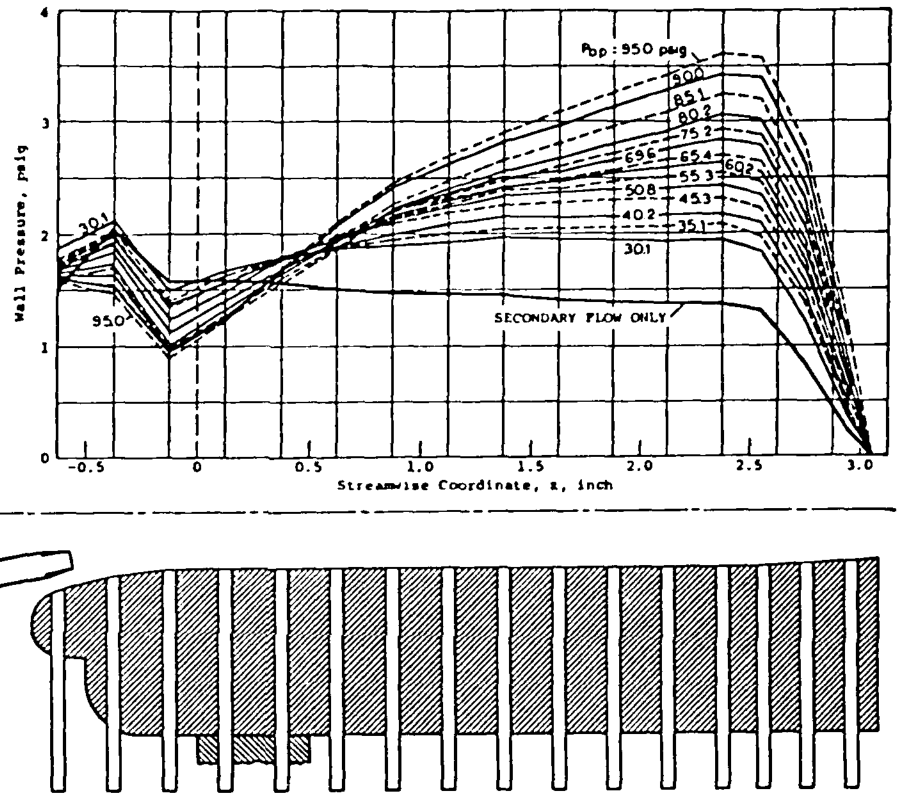
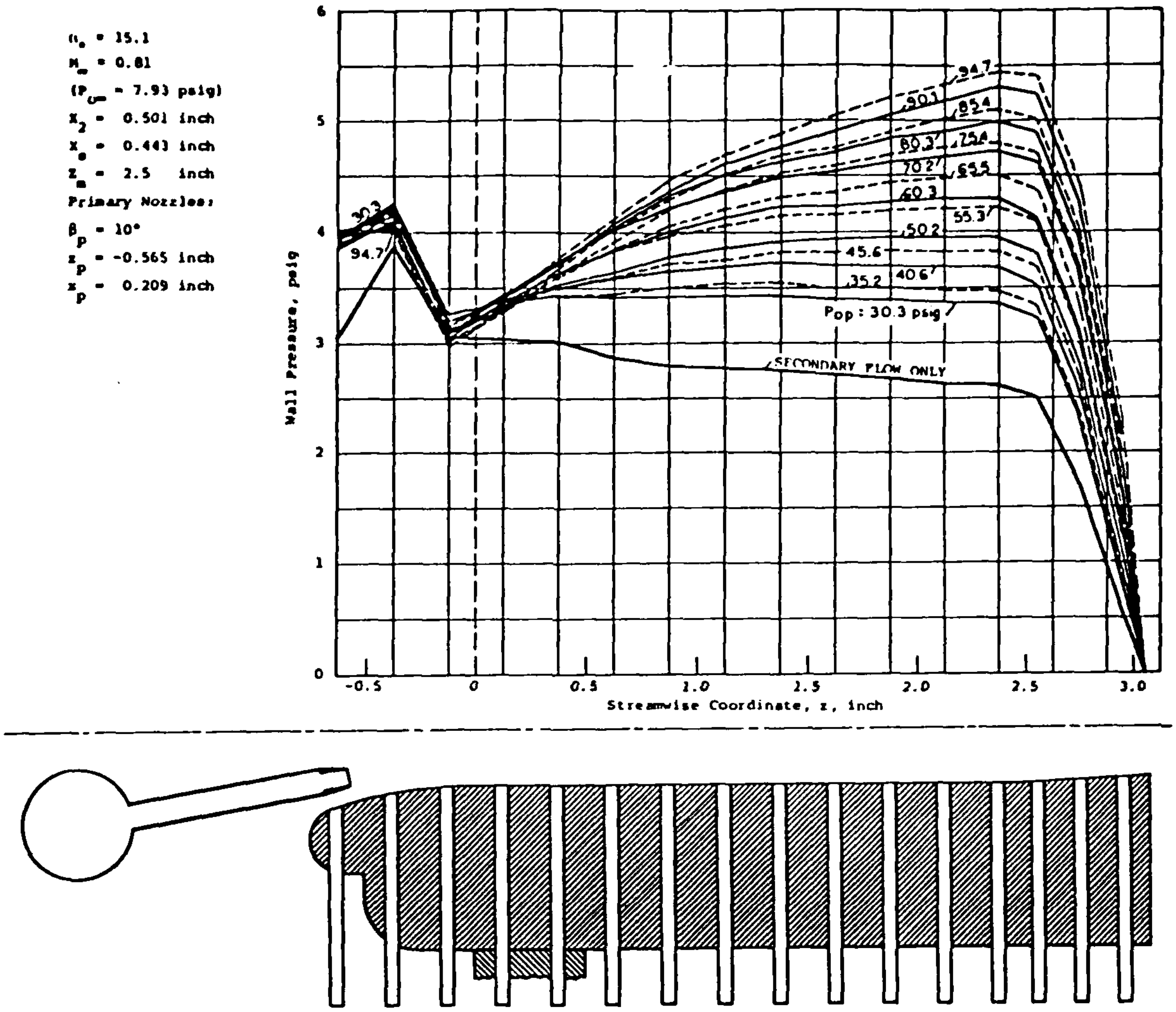
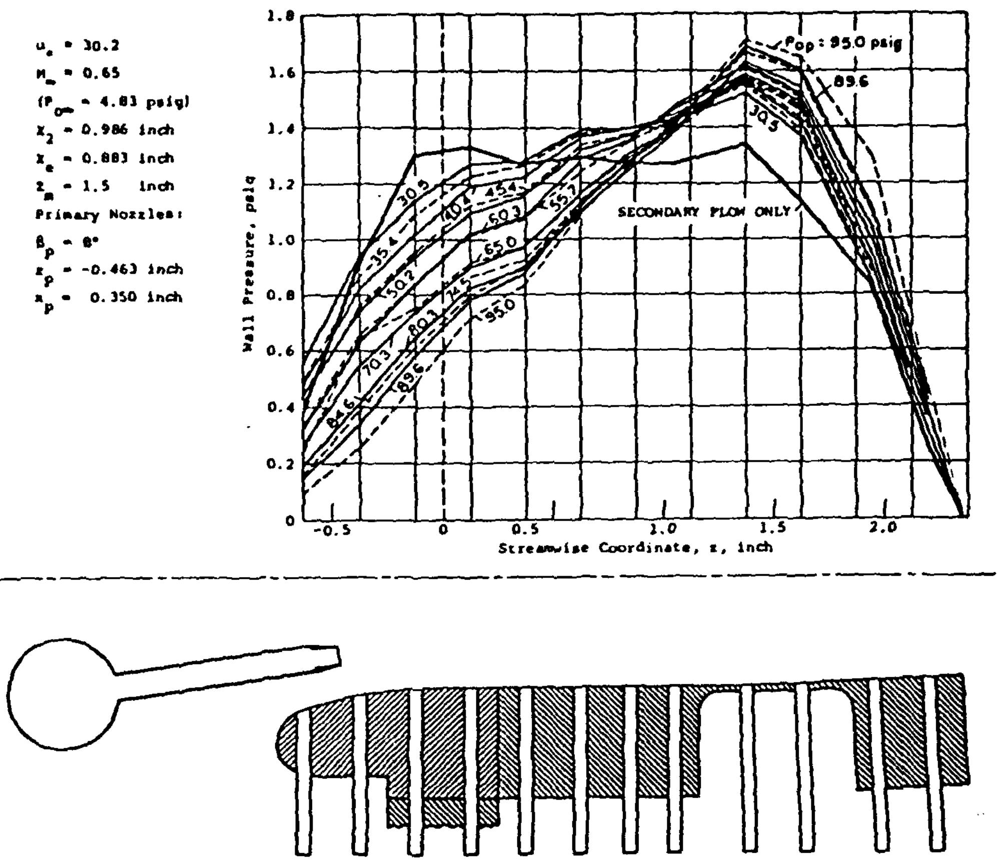


Figure 7



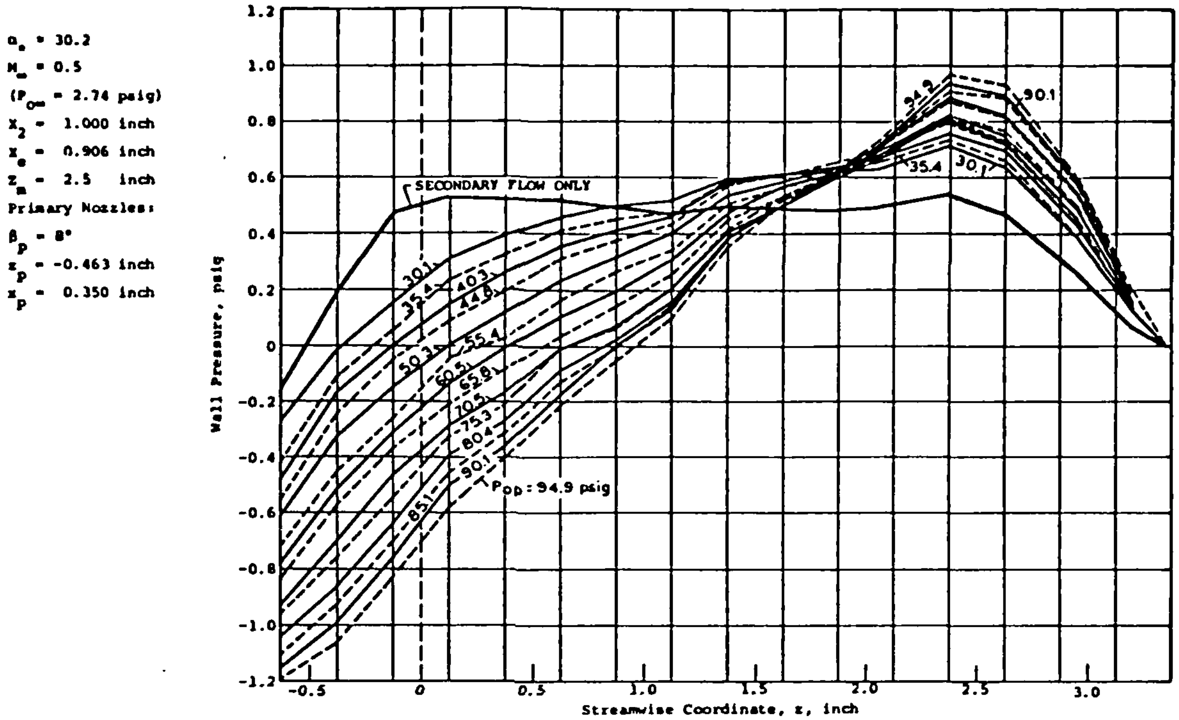
α_e = 15.1
M_∞ = 0.81
($P_{0\infty}$ = 7.93 psig)
X_2 = 0.501 inch
X_e = 0.443 inch
Z_m = 2.5 inch
Primary Nozzles:
β_p = 10°
z_p = -0.565 inch
x_p = 0.209 inch
94.7
90.1
85.4
80.3
75.4
70.2
65.5
60.3
55.3
50.2
45.6
40.6
35.2
30.3
Pop : 30.3 psig
SECONDARY FLOW ONLY
Wall Pressure, psig
Streamwise Coordinate, z, inch

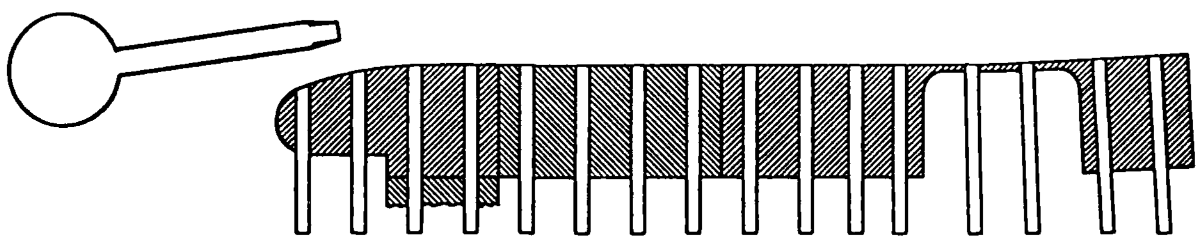
Figure 8



u_e = 30.2
M_∞ = 0.65
(P_0∞ = 4.83 psig)
X_2 = 0.986 inch
X_e = 0.883 inch
z_m = 1.5 inch
Primary Nozzles:
β_p = 8°
z_p = -0.463 inch
x_p = 0.350 inch
P_op : 95.0 psig
89.6
30.5
35.4
40.4
45.4
50.3
55.7
65.0
74.5
80.3
84.6
89.6
95.0
SECONDARY FLOW ONLY
Wall Pressure, psig
Streamwise Coordinate, z, inch
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
-0.5
0.5
1.0
1.5
2.0

Figure 9


α_s = 30.2
M_∞ = 0.5
($P_{O\infty}$ = 2.74 psig)
X_2 = 1.000 inch
x_e = 0.906 inch
z_m = 2.5 inch
Primary Nozzles:
β_p = 8°
z_p = -0.463 inch
x_p = 0.350 inch
Wall Pressure, psig
Streamwise Coordinate, z, inch
SECONDARY FLOW ONLY
P_{Op} = 94.9 psig



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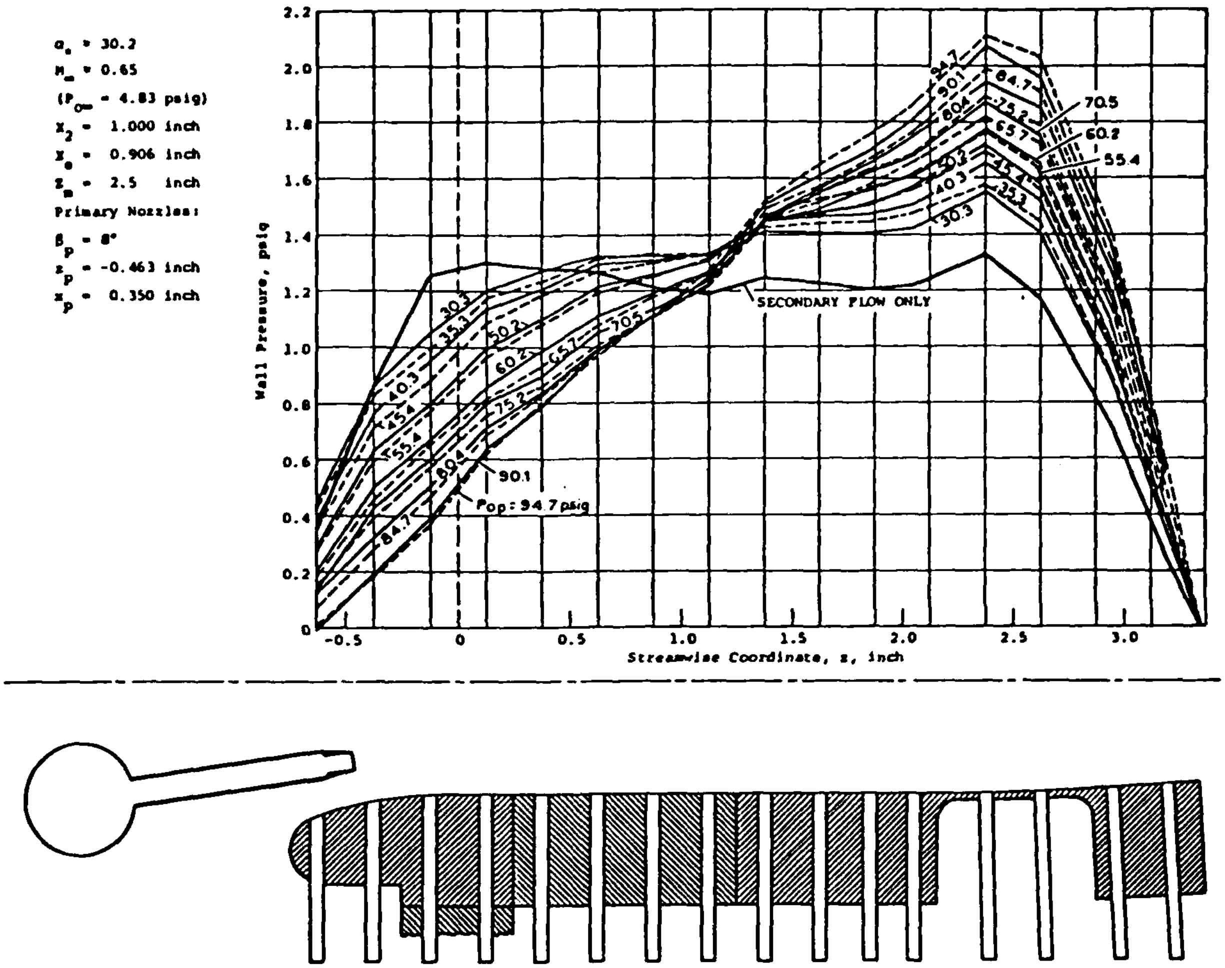
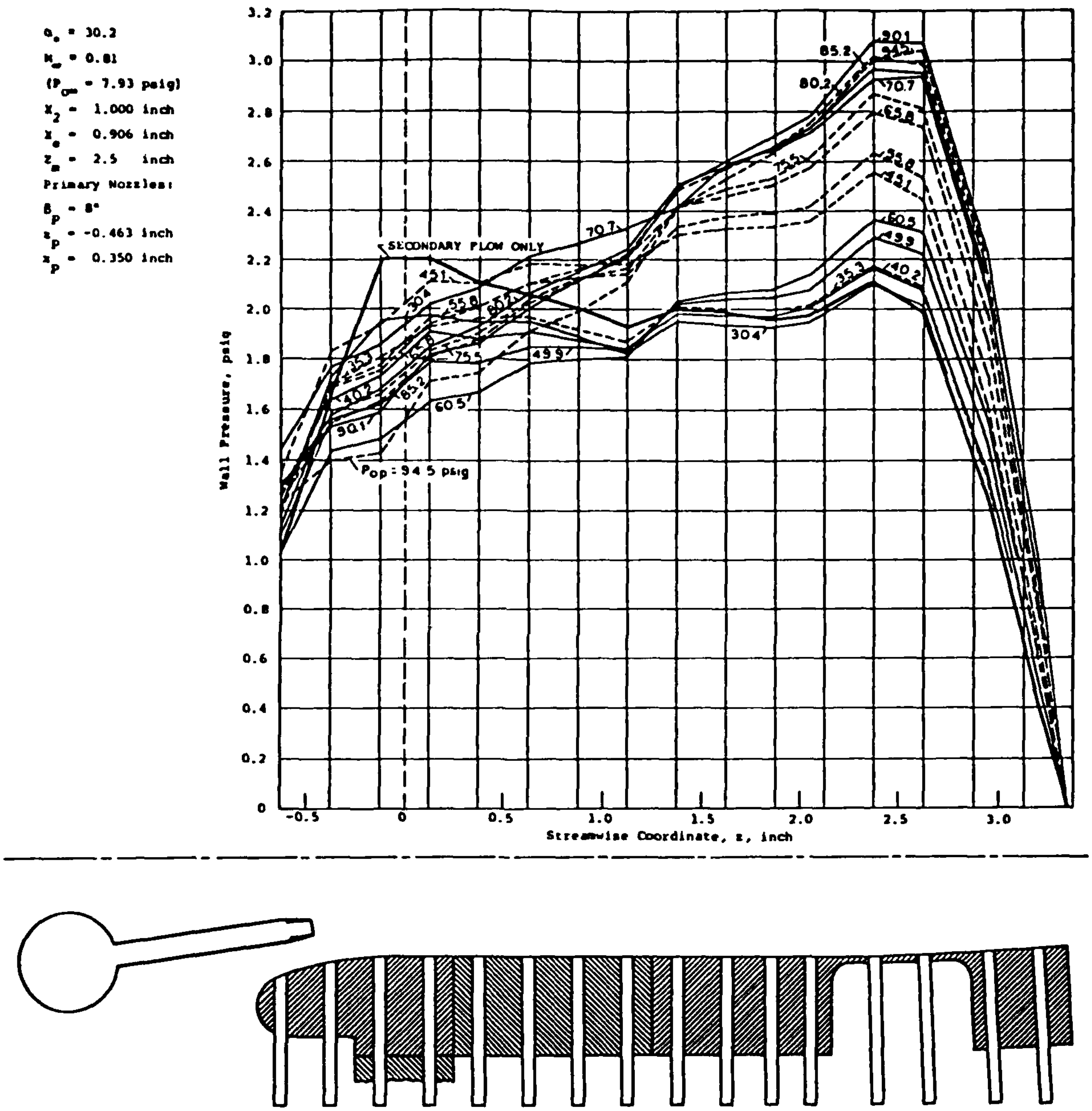


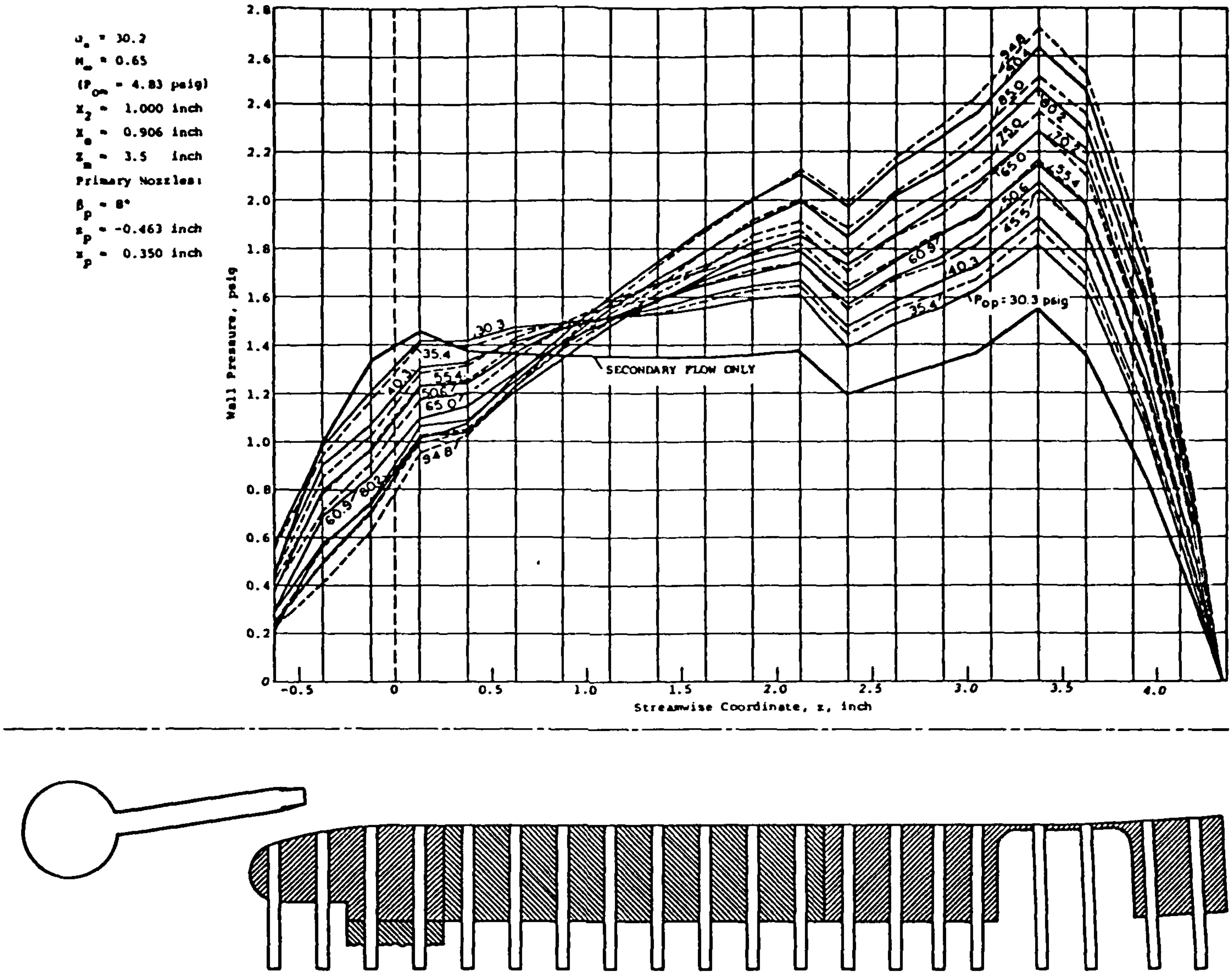
α_s = 30.2
M_∞ = 0.65
($P_{0\infty}$ = 4.83 psig)
X_2 = 1.000 inch
X_e = 0.906 inch
Z_m = 2.5 inch
Primary Nozzles:
β_p = 8°
z_p = -0.463 inch
x_p = 0.350 inch
Wall Pressure, psig
Streamwise Coordinate, z, inch
SECONDARY FLOW ONLY
Pop: 94.7 psig

Figure 11



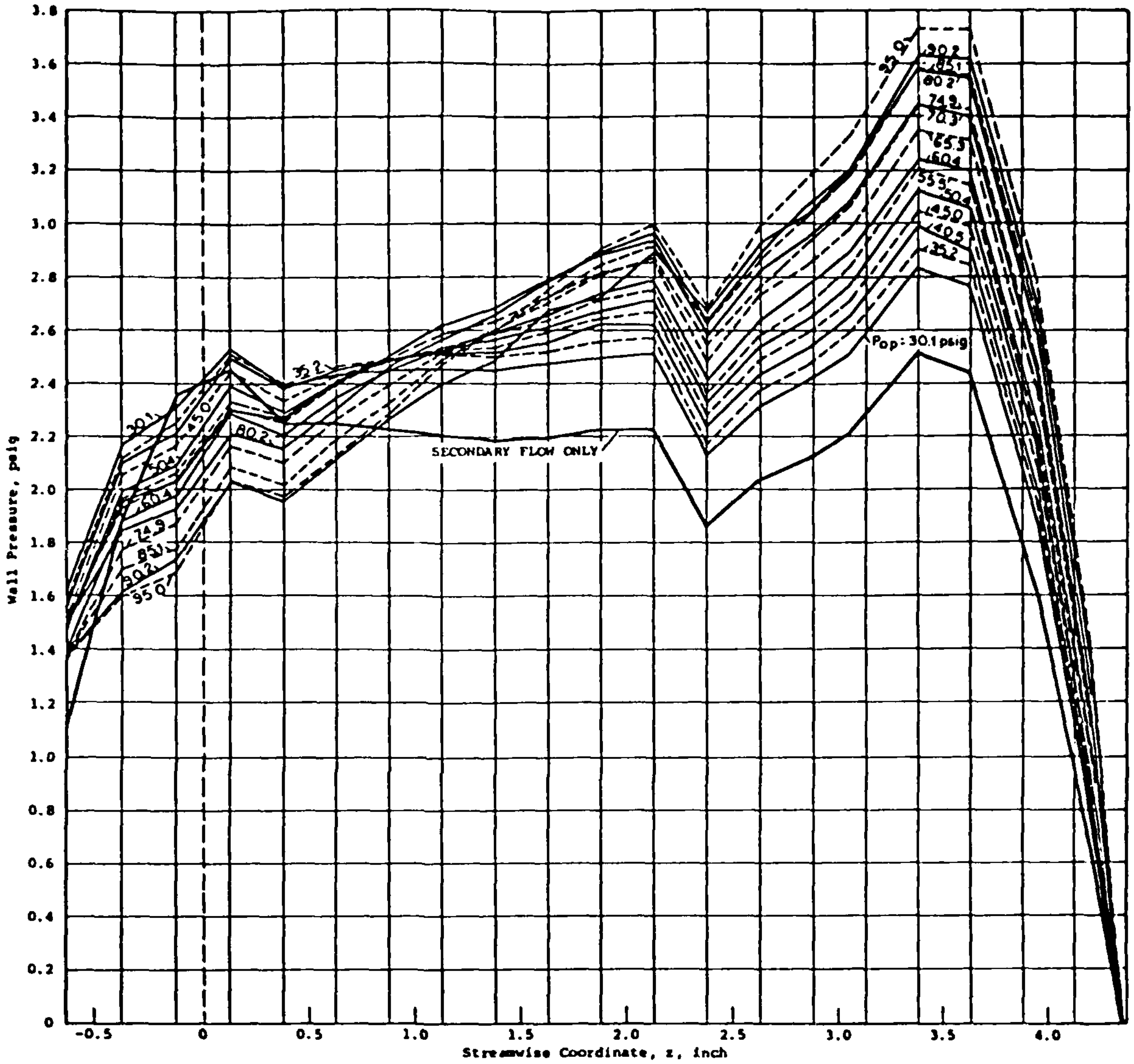
a_s = 30.2
M_∞ = 0.81
($P_{o\infty}$ = 7.93 psig)
X_2 = 1.000 inch
X_e = 0.906 inch
z_m = 2.5 inch
Primary Nozzles:
β_p = 8°
z_p = -0.463 inch
z_p = 0.350 inch
SECONDARY FLOW ONLY
P_{op} = 94.5 psig
Wall Pressure, psig
Streamwise Coordinate, z, inch

Figure 12

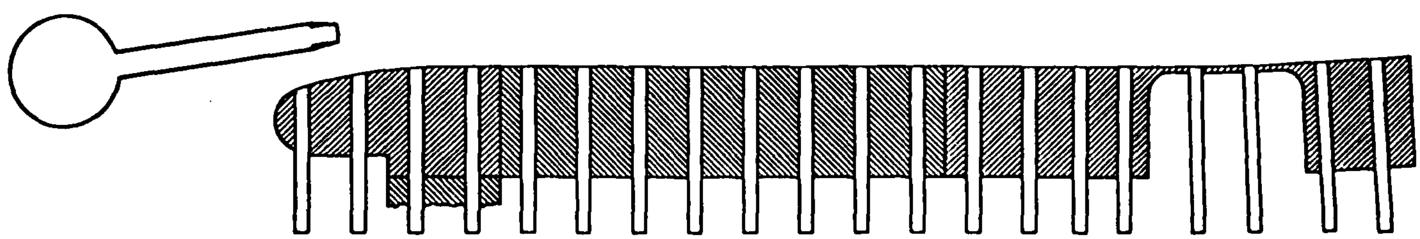


σ = 30.2
M = 0.65
(P = 4.83 psig)
X2 = 1.000 inch
X = 0.906 inch
Z = 3.5 inch
Primary Nozzles:
βp = 8°
zp = -0.463 inch
xp = 0.350 inch
Wall Pressure, psig
Streamwise Coordinate, z, inch
SECONDARY FLOW ONLY
Pop = 30.3 psig

Figure 13



$Q_s = 30.2$
$M_\infty = 0.81$
$(P_{o\infty} = 7.93$ psig)
$X_2 = 1.000$ inch
$X_e = 0.906$ inch
$z_m = 3.5$ inch
Primary Nozzles:
$\beta_p = 8°$
$z_p = -0.463$ inch
$x_p = 0.350$ inch



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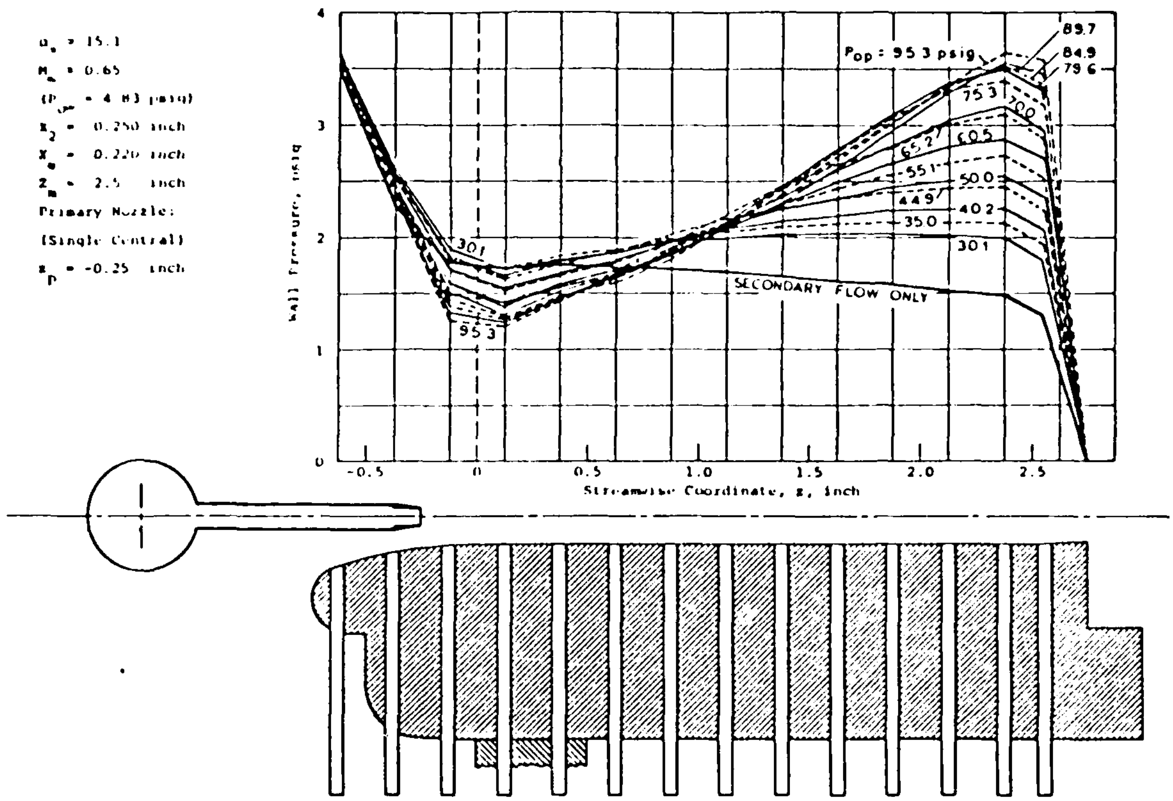
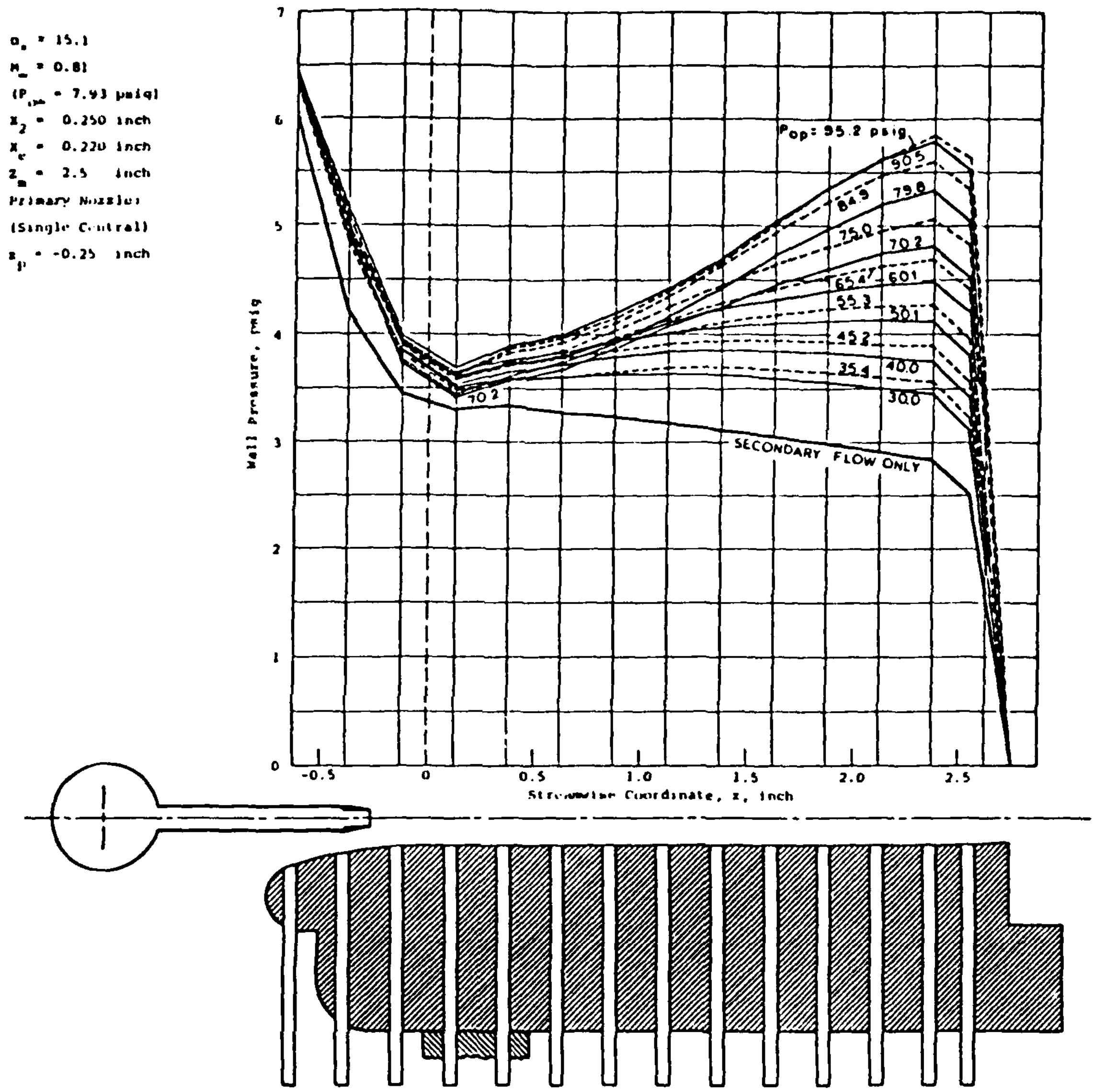


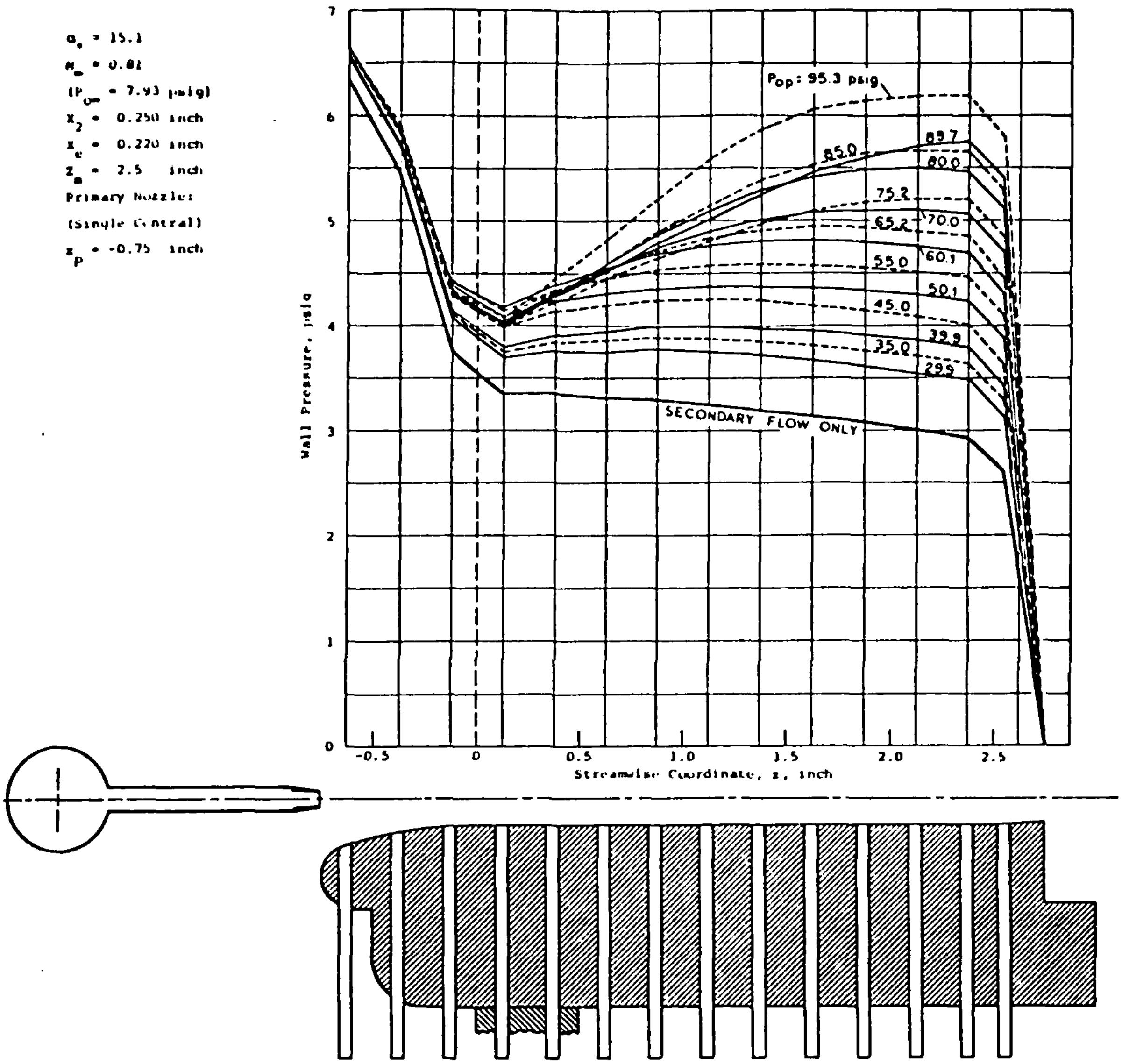
α_e = 15.1
M_a = 0.65
(P_{oa} = 4.83 psig)
r_2 = 0.250 inch
X_e = 0.220 inch
Z_m = 2.5 inch
Primary Nozzle:
(Single Central)
z_p = -0.25 inch
Wall Pressure, psig
Streamwise Coordinate, z, inch
P_{op} = 95.3 psig
89.7
84.9
79.6
75.3
70.0
65.2
60.5
55.1
50.0
44.9
40.2
35.0
30.1
95.3
SECONDARY FLOW ONLY

Figure 15



α_s = 15.1
M_∞ = 0.81
($P_{t\infty}$ = 7.93 psig)
X_2 = 0.250 inch
X_c = 0.220 inch
Z_m = 2.5 inch
Primary Nozzle:
(Single Central)
Z_p = -0.25 inch
P_{op} = 95.2 psig
90.5
84.9
79.8
75.0
70.2
65.4
60.1
55.3
50.1
45.2
40.0
35.4
30.0
70.2
SECONDARY FLOW ONLY
Wall Pressure, psig
Streamwise Coordinate, x, inch

Figure 16



α_e = 15.1
M_∞ = 0.81
($P_{0\infty}$ = 7.93 psig)
x_2 = 0.250 inch
x_e = 0.220 inch
z_m = 2.5 inch
Primary Nozzle:
(Single Central)
z_p = -0.75 inch
P_{op}: 95.3 psig
89.7
85.0
80.0
75.2
70.0
65.2
60.1
55.0
50.1
45.0
39.9
35.0
29.9
SECONDARY FLOW ONLY
Wall Pressure, psig
Streamwise Coordinate, z, inch
0
1
2
3
4
5
6
7
-0.5
0
0.5
1.0
1.5
2.0
2.5

Figure 17

Q_s = 30.2

M_∞ = 0.65

($P_{C\infty}$ = 4.83 psig)

X_2 = 0.501 inch

X_e = 0.440 inch

Z_m = 2.5 inch

Primary Nozzle:

(Single Central)

z_p = -0.25 inch

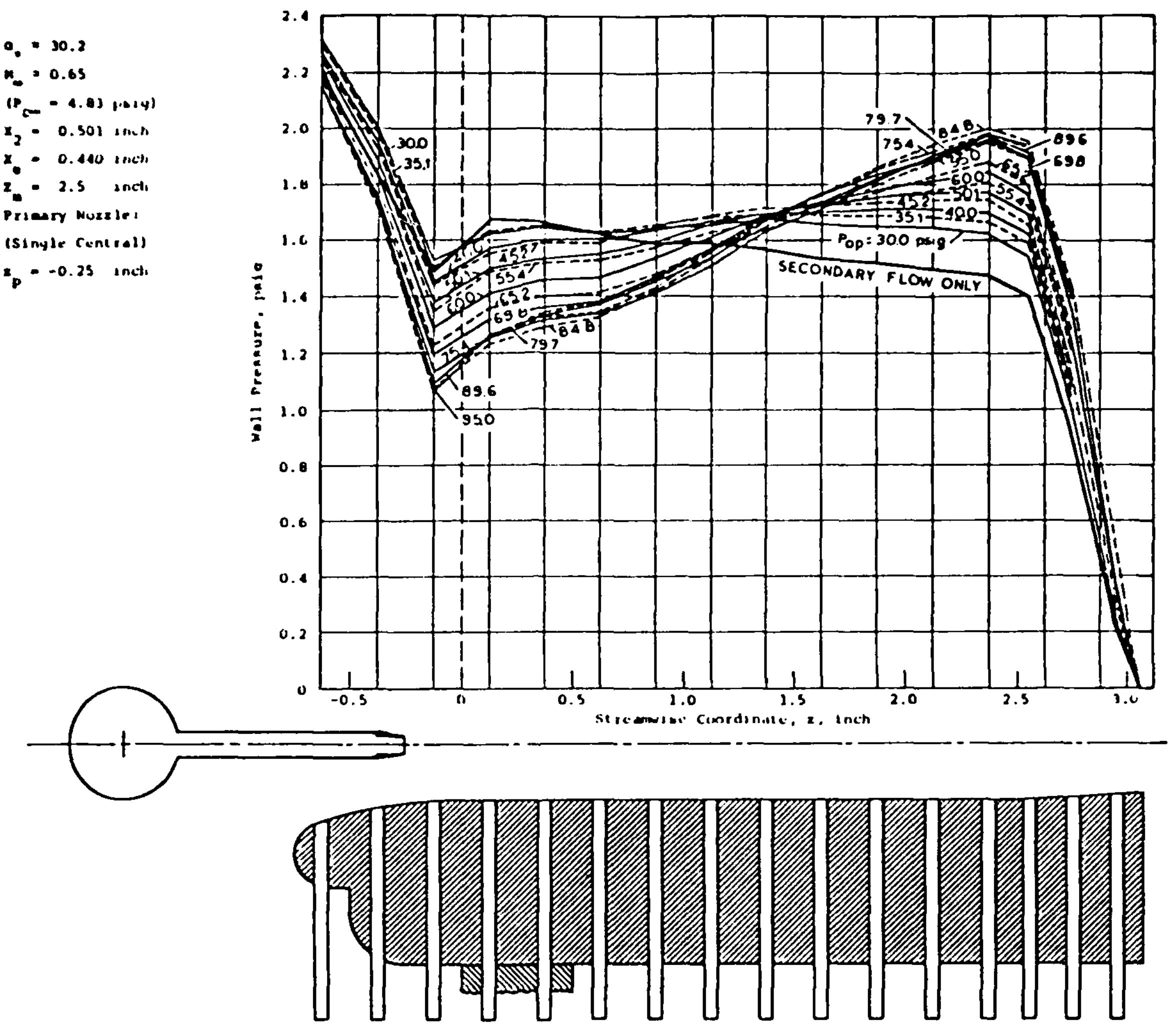


Figure 18

$\alpha_* \approx 30.2$

$M_\infty \approx 0.5$

$P_{op}/P_\infty = 6.1$

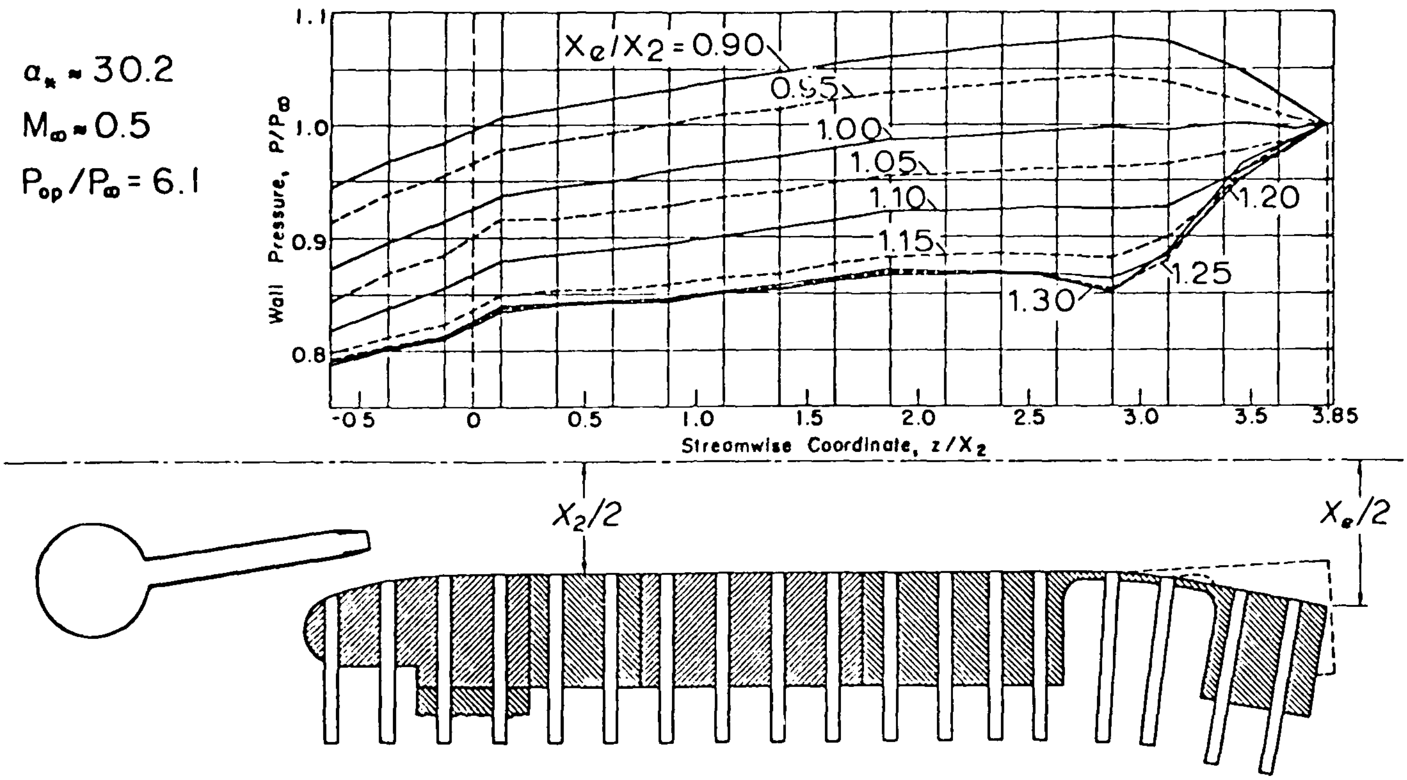
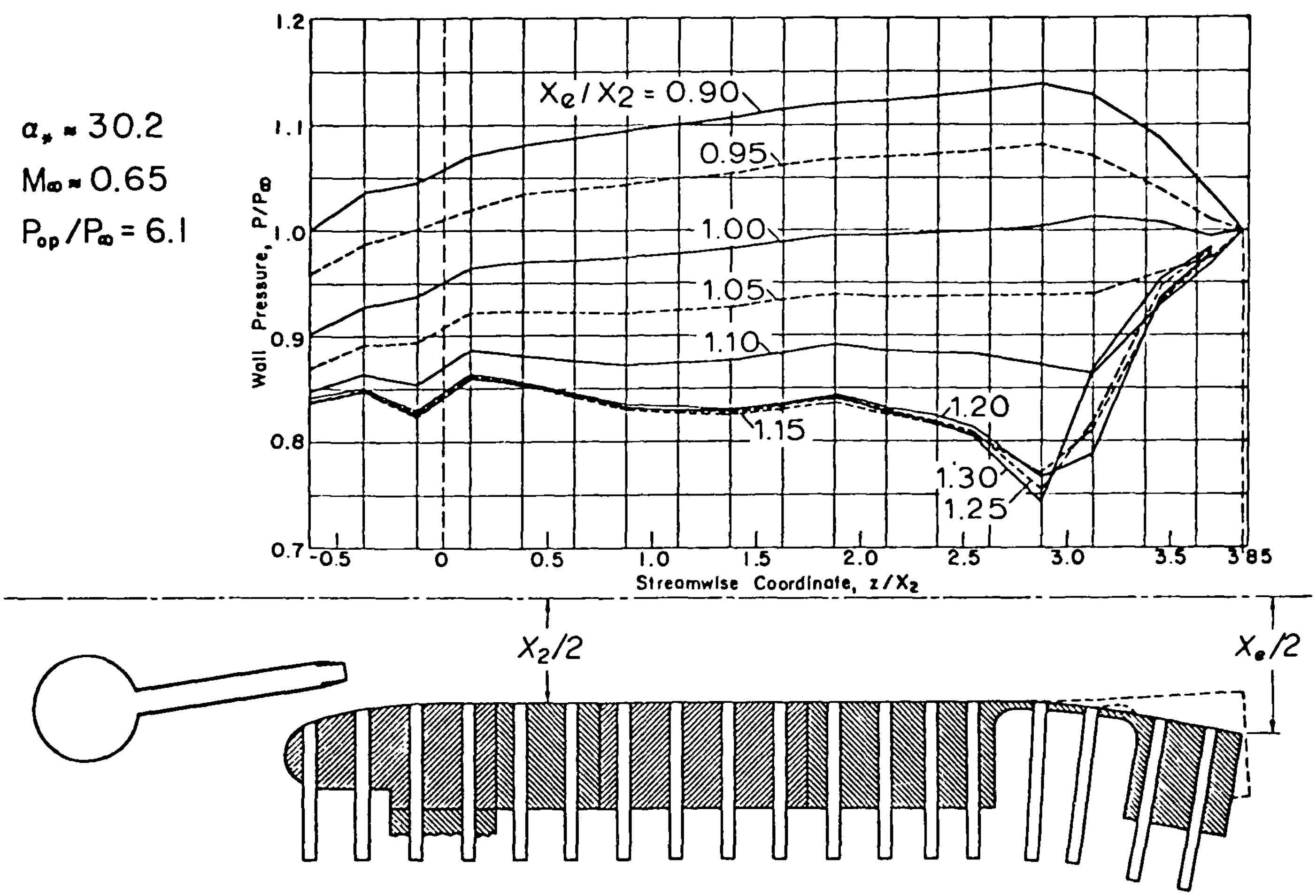
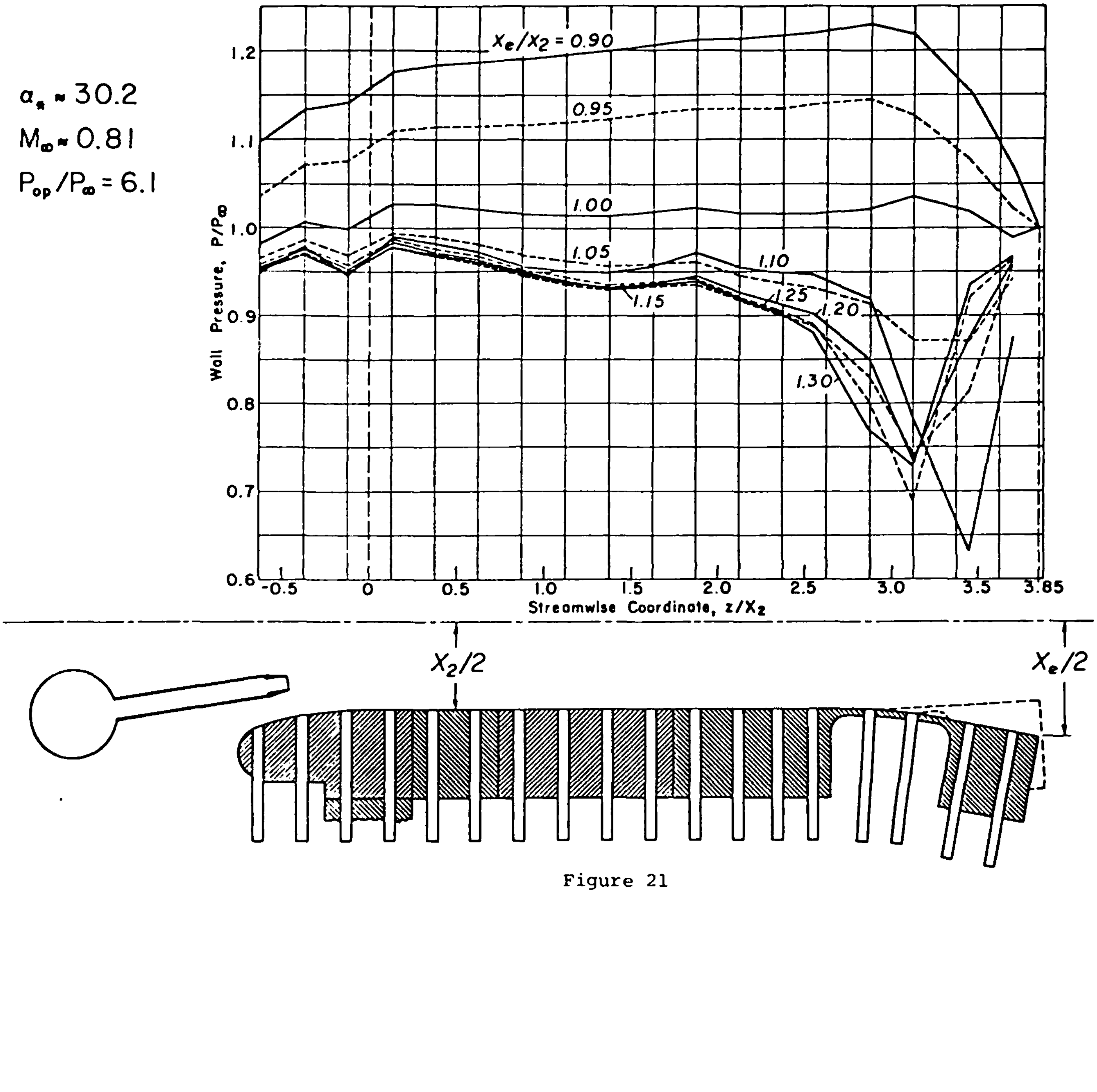


Figure 19



$\alpha_* \approx 30.2$
$M_\infty \approx 0.65$
$P_{op}/P_\infty = 6.1$
Wall Pressure, P/P_∞
Streamwise Coordinate, z/X_2
$X_e/X_2 = 0.90$
0.95
1.00
1.05
1.10
1.15
1.20
1.25
1.30
$X_2/2$
$X_e/2$

Figure 20



$\alpha_s \approx 30.2$
$M_\infty \approx 0.81$
$P_{op}/P_\infty = 6.1$
$X_e/X_2 = 0.90$
0.95
1.00
1.05
1.10
1.15
1.25
1.20
1.30
Wall Pressure, P/P_∞
Streamwise Coordinate, z/X_2
$X_2/2$
$X_e/2$

Figure 21

P_{op} = 70.5 psig

P_{op} = 75.2 psig

P_{op} = 79.9 psig

P_{op} = 85.1 psig

Figure 22. Formation of Starting Shock Wave
$M_\infty = 0.5$; $\alpha_* = 7.55$

Examples of Ejector Flows under the Second Solution

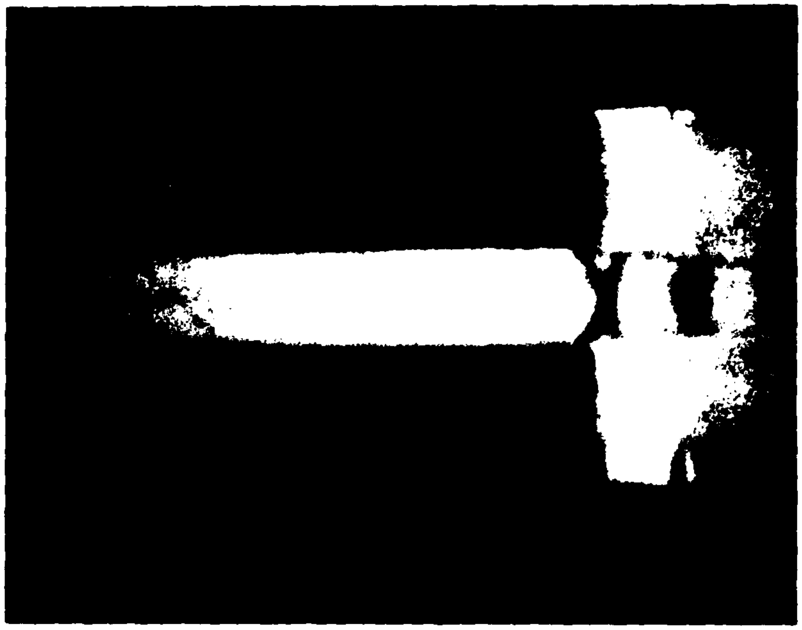


Figure 23. $M_\infty = 0.65$, $\alpha_* = 7.55$, $X_2 = X_e = 0.25"$, $Z_m = 2.5"$, $P_{op} = 105$ psig

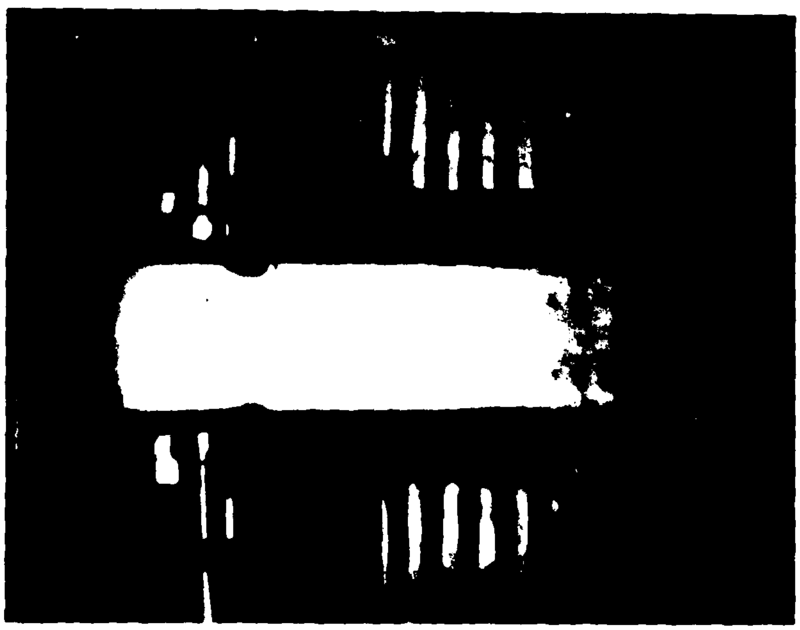


Figure 24. $M_\infty = 0.81$, $\alpha_* = 30.2$, $X_2 = 1"$, $X_e = 1.1"$, $Z_m = 3"$, $P_{op} = 75$ psig